

DO CLUSTER GALAXIES HAVE EXTENDED DARK HALOS?

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We present the results of the application of the methodology introduced by Natarajan & Kneib (1997) to interpret local perturbations to the cluster shear field resulting from mass associated with individual cluster galaxies. The lensing signal is used to place new constraints on the average mass-to-light ratio and spatial extents of the dark matter halos associated with morphologically-classified early-type cluster members in the Abell cluster AC114. The total mass of a fiducial L^* cluster spheroidal galaxy is found to be largely contained within ~ 15 kpc radius halo ($\sim 8\text{--}10 R_e$) with a mass-to-light ratio $M/L_V \sim 15^{+10}_{-4}$ (90 % c.l.) in solar units within this radius. Comparisons with similar estimates for field galaxies suggests that the cluster galaxies in AC114 may possess less extensive and less massive halos. Additionally, there is some indication that, at a fixed luminosity, S0 galaxies are less extended than ellipticals, suggesting a difference in the efficiency of tidal stripping for different galaxy types. These results enable us to probe the variation of the mass-to-light ratio with scale via gravitational lensing methods. Therefore, the prospects for constraining the mass density of the Universe and understanding galaxy evolution using these gravitational lensing methods are very promising.

1 Introduction and Motivation

The primary motivation for this analysis is to examine the importance of galaxy-scale halos in defining the distribution of mass in clusters on intermediate scales ($\simeq 50$ kpc) across a range of environments within clusters from the core regions to the lower density outskirts. Using gravitational lensing observations as a primary tool, our technique considers perturbations associated with an ensemble of cluster galaxies within a smooth global cluster potential. The important physical question that one hopes to address is whether the mass-to-light ratio (M/L) of galaxies (measured within a large effective aperture) varies significantly between high density cluster regions and the field. Environmental variation of the M/L ratio of a galaxy might be expected if these galaxies presently found in dense regions suffered more complex interaction histories leading to a redistribution of the associated gaseous, stellar and dark matter components (c.f. Moore et al. 1996). One possibility is that the extended dark halo would be preferentially removed and redistributed, leading to a reduction in the M/L ratio compared to that found for isolated galaxies of the same morphological type. However, the scale on which this redistribution occurs (and hence the ‘granularity’ of the resultant dark matter distribution within the cluster) is unclear and has important implications for our understanding of how clusters assemble and evolve.

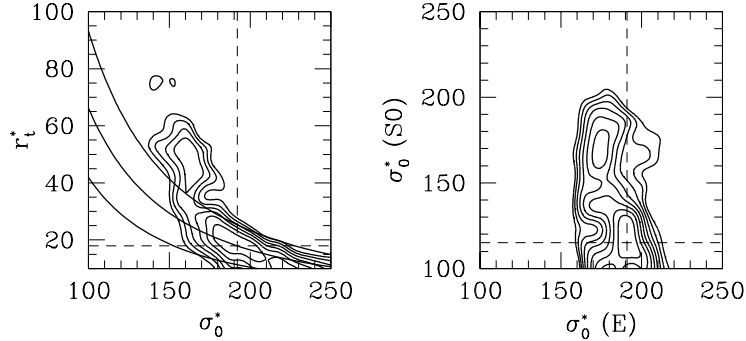


Figure 1: Left Panel: Maximum-likelihood retrieval of the fiducial parameters for cluster galaxies in AC114: the likelihood peaks at $r_t^* \sim 20$ kpc and $\sigma_0^* \sim 190$ km s $^{-1}$; and the inner 3 contour levels correspond respectively to 60%, 80% and 90% confidence limits. The galaxy models used in this case correspond to constant mass-to-light ratio which are the overplotted solid curves for $M/L_V = 10, 17$ & 23 (increasing from bottom to top); Right Panel: Parameters recovered for the sub-samples: the cluster galaxies were split into 2 primary morphological classes the E's and the S0's. Combined optimization for their respective fiducial velocity dispersions yields: $\sigma_0^*(E) \sim 190$ km s $^{-1}$ and $\sigma_0^*(S0) \sim 120$ km s $^{-1}$. The inner 3 contours correspond to 60%, 80% and 90% confidence limits.

2 Brief sketch of the technique

Our technique involves quantifying the ‘local’ weak lensing induced by the dark halos around bright cluster galaxies. A measure of these small-scale perturbations can be derived from the statistical distribution of the shapes of faint background galaxies. We use the maximum-likelihood techniques developed in the theoretical discussion by Natarajan & Kneib (1995, 1997) and correlate the local perturbations with cluster galaxies of known morphology and luminosity. In this way, we provide new constraints on the M/L and the extent of dark halos in cluster galaxies. Besides incorporating both strong and weak lensing constraints simultaneously, further observational input from the correlations for early-type galaxies that inhabit the Fundamental Plane are used in the analysis. We have successfully applied these techniques to a new wide-field *Hubble Space Telescope* (*HST*) image of the rich cluster AC114 ($z = 0.31$). A detailed model of the large-scale mass distribution within the cluster using the numerous strongly-lensed features visible in the *HST* data is constructed and analyzed.

3 Results and Discussion

We report the first detection of the signature of extended dark halos around galaxies in AC114. From our analysis we find that a L^* spheroidal cluster galaxy has a total mass of $M \sim (4.9^{+3.1}_{-1.3}) \times 10^{11} M_\odot$, and a $M/L_V \sim 15^{+10}_{-4} (M/L)_\odot$ (90 % c.l.). We find that the **total** mass of a fiducial L^* cluster spheroidal is primarily contained within ~ 15 kpc, with some indication that the halos of the S0 population may be more truncated than those of the ellipticals. Comparisons with similar estimates for field galaxies suggests that the cluster galaxies in AC114 may possess less extensive and less massive halos. Comparing the total mass in cluster galaxies within 250 kpc of the center (down to the

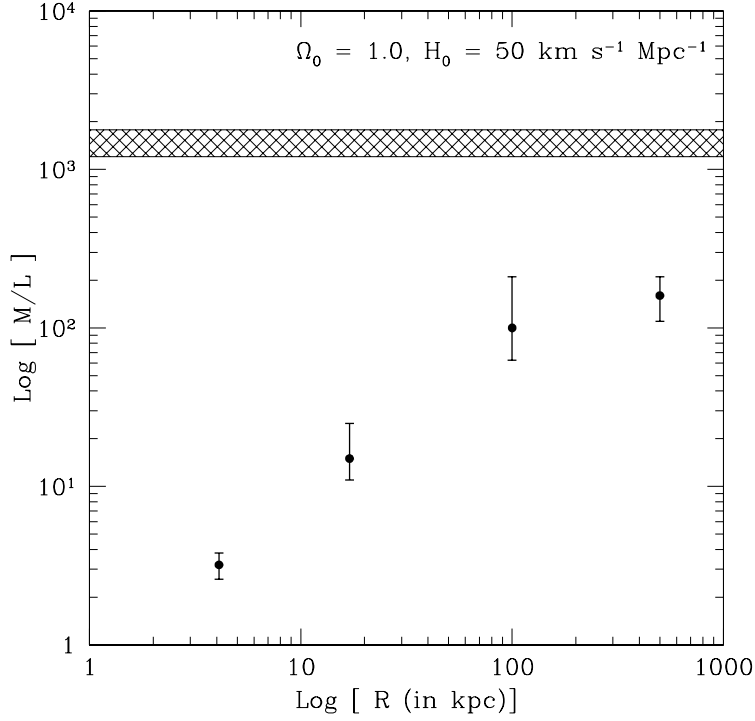


Figure 2: The variation of the M/L ratio with scale as probed by **gravitational lensing** methods. The point on the smallest scale (4.1 kpc) is from the M/L determined at the Einstein radius for the galaxy lens HST14176 [Hjorth & Kneib 1998]; the second point at 17 kpc is from the galaxy-galaxy lensing in the cluster in AC114 [NKSE 97]; the third from galaxy-galaxy lensing in the field [BBS 96] and the final point is the total mass-to-light ratio of the cluster AC114 computed at 500 kpc [NKSE 97]. The cross-hatched region in the plot is the global mass-to-light ratio required in order to close the Universe.

magnitude limit of our selection criterion) to the total mass of the cluster, we estimate that approximately 11% of the mass of the cluster is bound to individual cluster galaxies. This fraction has important consequences for the rate of galaxy interactions and hence the evolution of the cluster on the whole. In Fig. 2, the variation of the mass-to-light ratio with scale as probed via gravitational lensing using both strong and weak lensing effects is plotted [also see N. Bahcall's contribution in this proceeding for comparison with other methods]. A more detailed discussion of the observed trend in the context of implications for cosmology and galaxy evolution as well as comparison with other determinations from purely dynamical methods and X-rays for estimating the total mass is presented elsewhere (Natarajan, P. 1997).

These first results on the properties of galaxy halos within clusters from lensing are very encouraging. We are therefore extending our analysis using both observations of galaxies in the central regions of rich clusters at $z = 0.17$ – 0.56 (Natarajan, Kneib & Smail 1998) and across a range of environments within a number of clusters at $z \sim 0.3$. These two samples will provide insights into the role of changes in halo properties in the evolution of both cluster spheroids and disk galaxies, as well as the variation of these effects with local environment. The hope of future expansion of this technique appears good with the proposed installation of the the Advanced Camera for Survey *ACS*

in the next *HST* Servicing Mission, which will be able to cover a wider field providing the ideal data-sets for such studies. Therefore, the prospects for understanding the evolution of galaxy halos from field galaxies to cluster cores and hence the radial variation of the mass-to-light ratio are promising.

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